

**2004 Annual Project Summary**  
**Active Deformation and Earthquake Potential of the Southern Los Angeles**  
**Basin, Orange County, California**

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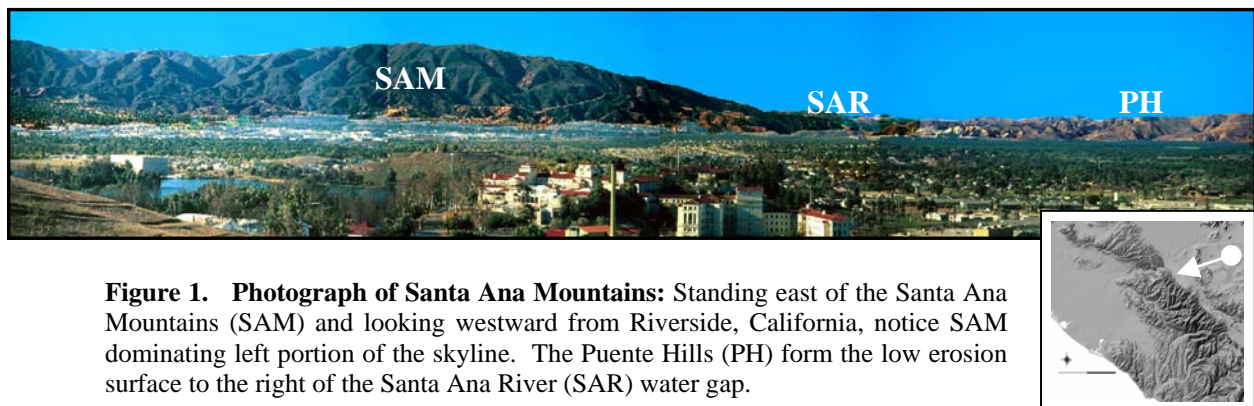
with contributions from Lewis Owen, UC Riverside and Cincinnati University

**Keywords:** Tectonic geomorphology, Tectonic structures, Age Dating,  
Neotectonics

### **Investigations Undertaken**

In 2004 we continued our previous work under a no-cost extension of the project. Most of the work during the extension was focused on collecting samples for OSL dating, doing preliminary analysis of the results, and collecting a second set of samples to confirm initial results. Dating of the second set of samples is currently in progress. This report describes our geomorphic analysis methods, sample collection activities, and presents preliminary results from the first set of samples. A companion report based on our 2004 funding describes preliminary interpretations of the data.

The southern Los Angeles (LA) basin has been characterized as moderate to low seismic risk (Petersen and Wesnousky, 1994; WGCEP, 1995). This assessment is based on minimal knowledge of the neotectonics, and may be the result of a gap in knowledge rather than a lack of earthquake sources. Preliminary work suggests that several late Quaternary structures in the southern LA basin have significant rates of deformation but are poorly understood or unrecognized by seismic mitigation professionals and scientists. The earthquake potential posed by these structures is potentially disastrous for the nearly three million people who live and work in Orange County. We are addressing this knowledge gap by building on our recent work in the San Joaquin Hills (Grant et al., 1999; 2000; 2002) and Puente Hills (Gath, 1997; Gath et al., 1992) to identify and analyze other actively deforming structures in the southern LA basin.



**Figure 1. Photograph of Santa Ana Mountains:** Standing east of the Santa Ana Mountains (SAM) and looking westward from Riverside, California, notice SAM dominating left portion of the skyline. The Puente Hills (PH) form the low erosion surface to the right of the Santa Ana River (SAR) water gap.

Rising to a height of over 1,700 meters above sea-level, the Santa Ana Mountains (SAM) are the northernmost extent of the California Peninsular Ranges (figure 1) at the southeast margin of the Los Angeles basin (inset, figure 1). They rise nearly 900 meters above the heavily populated urban centers in Orange and Riverside counties, but neither their uplift rate nor uplift mechanism has been determined.

We have been conducting a quantitative tectonic geomorphologic analysis of the Santa Ana Mountains and foothills, including the Peralta Hills and Puente Hills (Figures 1 and 2). The pattern of stream development and channel response is one of the most sensitive indicators of active tectonic deformation. Using standard geomorphic tools and techniques listed in **Table 1**, we are analyzing the fluvial system to determine how active deformation has affected its pattern of development. Much of this analysis is being accomplished with GIS, using a combination of ArcView, Spatial Analyst and RiverTools software processing of 10 m and 30 m DEM data.

**Table 1:** Tectonic geomorphic analysis methods, southern margin LA basin

<ul style="list-style-type: none"> <li>• channel length, drainage basin area, and stream power (Hack, 1973; Ohmori, 1993)</li> <li>• marine and fluvial terrace morphology (Rockwell et al., 1984; Nicol et al., 1994; Rosenbloom and Anderson, 1994)</li> <li>• long river profiles (Personius, 1993; Merritts et al., 1994)</li> </ul>	<ul style="list-style-type: none"> <li>• stream channel deflections (Sieh and Jahns, 1984; McGill and Sieh, 1991)</li> <li>• topographic envelope, subenvelope, and residual maps (Bullard and Lettis, 1993; Bürgmann et al., 1994)</li> <li>• valley asymmetry (Cox 1994)</li> <li>• valley incision (Montgomery, 1994)</li> </ul>
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During the project period we have also mapped fluvial terraces in the northern SAM and Puente Hills, and contracted with Lewis Owen of UC Riverside (and more recently, Cincinnati University) for OSL (optically stimulated luminescence) dates. The terrace dating was jointly supported by USGS and SCEC. In 2003 we collected 7 samples from uplifted fluvial terraces along Santiago Creek in the Santa Ana Mountains, and on the north side of the Santa Ana River canyon in the Puente Hills. Ages of 6 samples are described in this report. One sample was destroyed in a laboratory accident. In 2004 we collected 7 additional samples for dating. Results are expected in early 2005.

## Results

Full results will be presented in at least 2 manuscripts and Final Technical Reports. One manuscript will describe the neotectonic development and geomorphic evolution of the southern Los Angeles basin, more popularly known as “The OC”. Another manuscript will focus on tectonic geomorphology of the Puente Hills and Santa Ana mountains.

### Geomorphic analysis

Our previous and ongoing work has identified several Quaternary structures that are poorly quantified for seismic risk: the San Joaquin Hills, Puente Hills, Peralta Hills, Loma Ridge, and Santa Ana Mountains. These areas are positive geomorphic features expressing evidence (terraces, wind gaps) of late Quaternary uplift. For our initial analysis, we examined the relationship between drainage basin area and time in the evolutionary development of a fluvial network. This approach has not been widely applied at a regional scale primarily because of the difficulty in providing temporal control for the drainage basins. Our study overcame this difficulty by developing and applying empirical relationships between drainage basin area and

age. The relationships were derived in the Puente Hills, where the Whittier fault has a known slip-rate. Next, we determined a relationship between basin area and main-channel age by dividing channel offset by the lateral slip rate of the fault, yielding a formula for basin age as a function of basin area. Finally, we applied this formula for basin age to the Santiago Creek drainage basin in an attempt to determine an approximate emergence age for the SAM. To check the age estimation for Santiago Creek, we also mapped fluvial fill terraces and geomorphic strath surfaces on both the Puente Hills and SAM. These terraces were correlated to the marine eustatic sea level curve used by Grant et al. (1999) for measuring the uplift rate and emergence of the San Joaquin Hills. The drainage basin evolution analysis and terrace correlations yielded emergence age of  $\sim 1.2$  Ma, and an uplift rate of approximately 0.4 mm/yr for the Puente Hills (Gath et al., 2002). Applying similar methods to the Santa Ana Mountains (work in progress) yields an uplift rate of  $\sim 0.3$  mm/yr. Uplift rates derived from terraces appear to be higher.

#### Age of Terraces for Measurement of uplift

To check the results of geomorphic analysis and terrace age correlations, we are measuring the uplift rates directly by dating the youngest terraces in the Santa Ana Mountains, and on the southern flank of the Puente Hills in Santa Ana River canyon (Figure 2, 3). *Initial* results and uplift rates are summarized in **Table 2**.

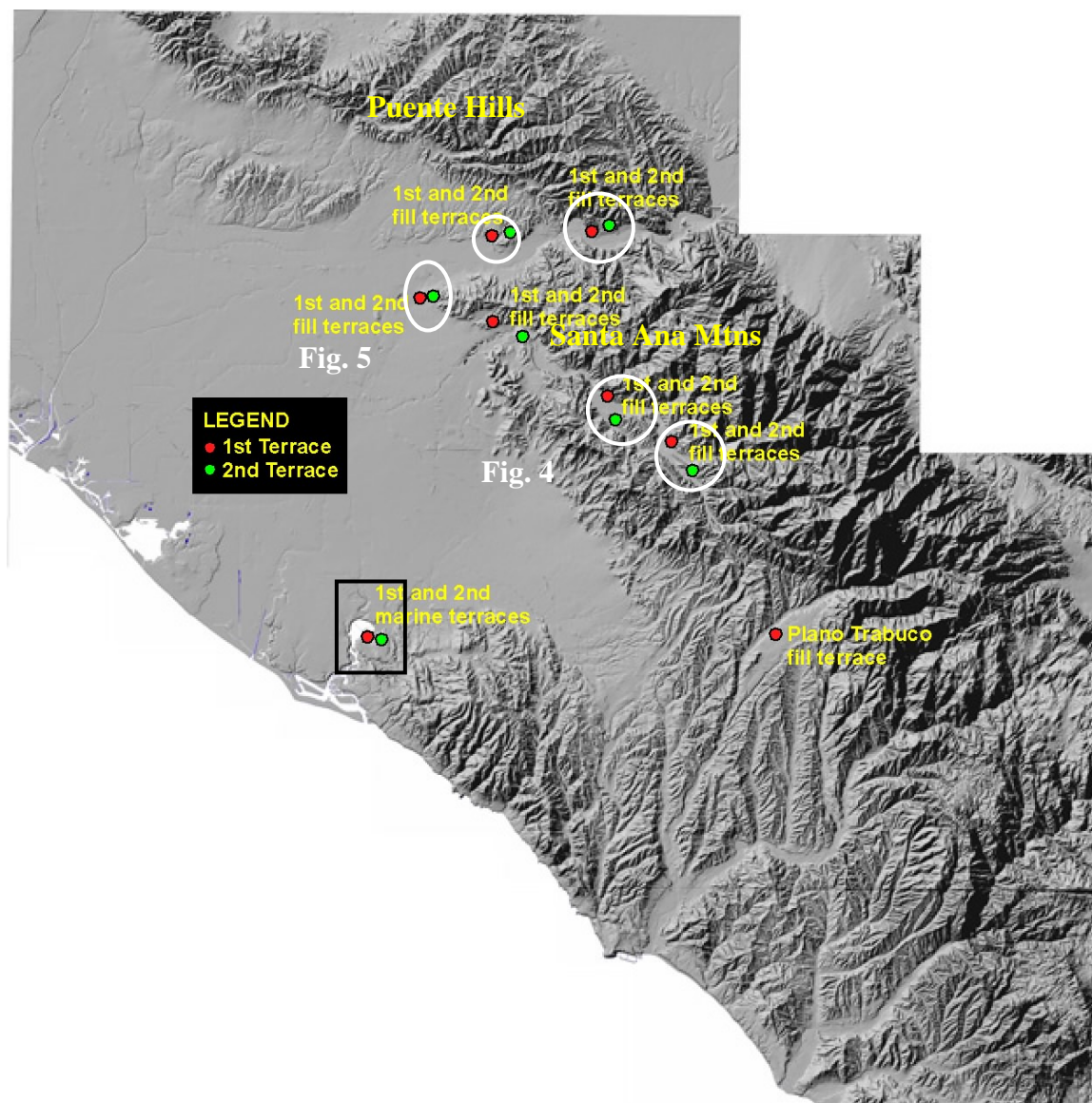
The Puente Hills have a suite of at least three fill terraces created by the Santa Ana River within Santa Ana Canyon (Gath, 1997). Genesis of the Puente Hills terraces is not readily explained by incision-only models. The preferred model is that these fill terraces were deposited during eustatic sea level high stands, incised by river response to low stands, and preserved by uplift in the intervening low-stands. OSL dating of the sediments forming the lowest of the Puente Hills terraces (Qt1) provided an age of  $31.9 \pm 4.8$  ka. The surface of the Qt1 terrace is approx. 38 m above equivalent modern base level of the Santa Ana River, indicating that it, and other higher terraces, have been uplifted since deposition as part of the Puente Hills block. The surface of a second terrace, Qt2, is approx. 15 m above Qt1, and 36 m above baselevel, as defined by the Santa Ana River. One sample collected from Qt2 yielded an age of  $38.0 \pm 3.9$  ka.

At least three similar fill terraces are present on the flank of the Santa Ana Mountains along the north side of Santiago Creek (Figures 2, 4). OSL dating yielded similar sediment ages of  $61.4 \pm 6.9$  ka and  $58.5 \pm 7.3$  ka for two sample locations taken only one meter apart near the base of the first emergent terrace, the surface of which is approximately 21 m (revised from 2003 report) above local base level. OSL dating of the sediments near the top of a correlative terrace resulted in an age of  $51.5 \pm 5.4$  ka. Santiago Creek is trapped between the uplifting Santa Ana Mountains and Loma Ridge. Although Santiago Creek would certainly have a response to the eustatic sea level fluctuations, it is likely that tectonic factors are partially responsible for terrace generation and preservation along Santiago Creek.

The Santa Ana River is deflected westerly by growth of the Olive anticline at the westernmost tip of Loma Ridge (Figure 5). This growth is accommodated by the Peralta Hills fault, geomorphically expressed as a 3 meter scarp (fold or fault scarp still uncertain) approximately 100 meters south of the sample location. Two OSL samples were collected from sediments comprising the lowest terrace where the Olive Anticline terminates westerly at the modern river floodplain level. The surface of the terrace is 15 meters above the local Santa Ana River base level. One sample was compromised in a lab accident, and analysis of the second sample indicates an age of at least 75 ka.

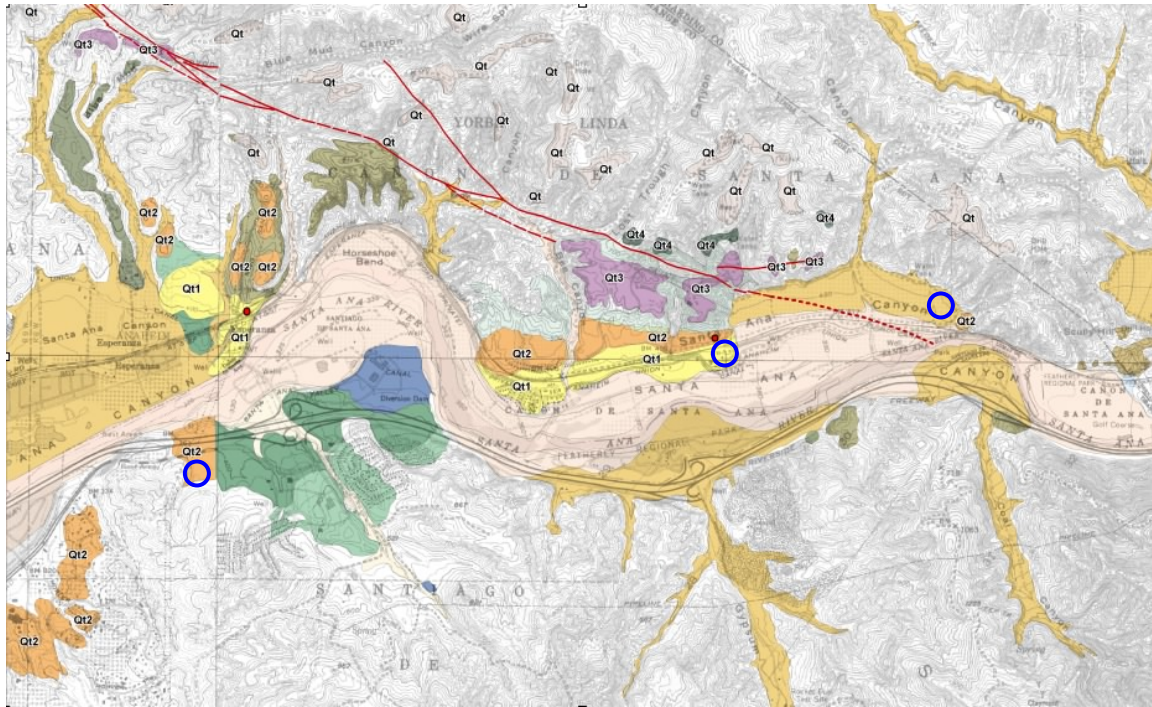
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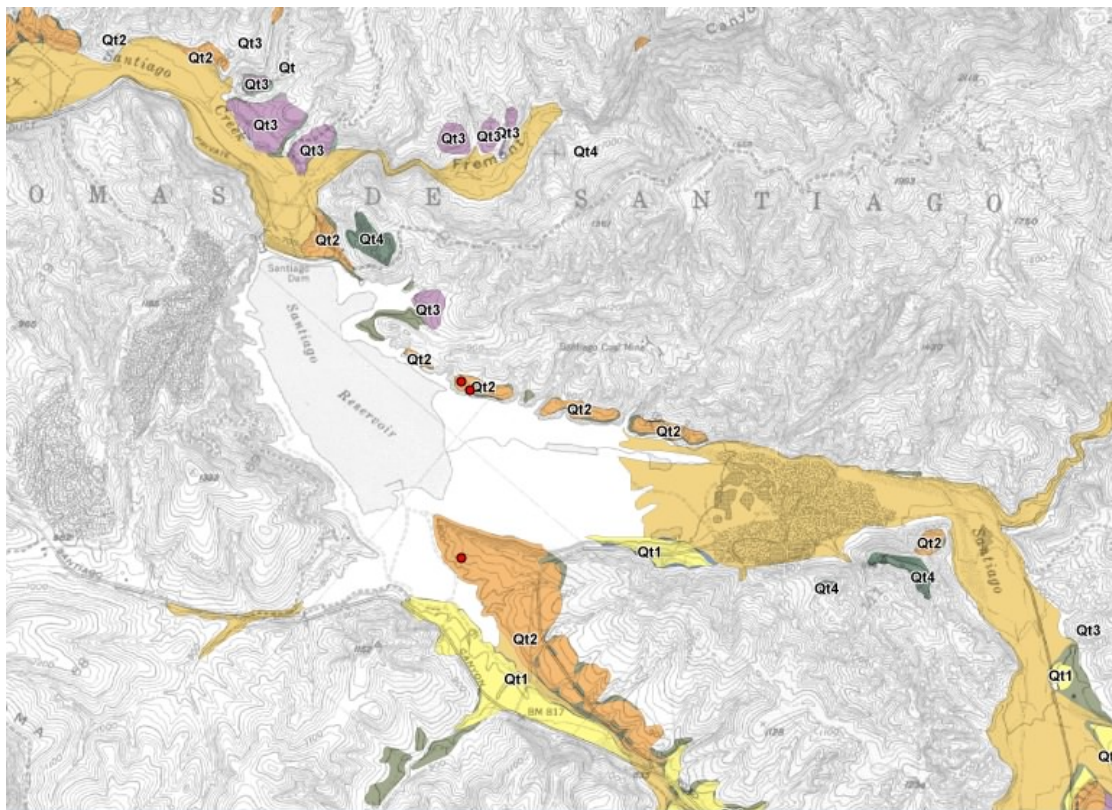


**Figure 2:** Approximate locations of sampling sites (dots) proposed for this project, and 2003 - 2004 sampling areas (enclosed by white circles) for OSL dating in the Santa Ana Mountains and Puente Hills. Proposed sampling sites in the San Joaquin Hills (black box) were eliminated from consideration because they appear to be too old for OSL dating.

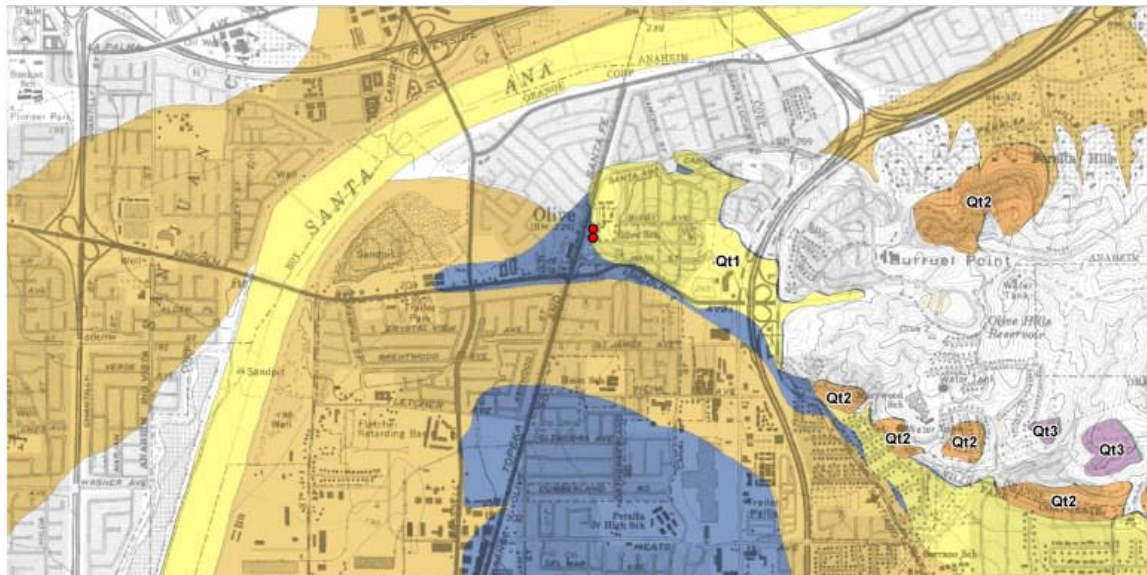




**Figure 3** Map of Santa Ana River (SAR) terraces in Santa Ana Canyon. The Santa Ana River Hills flows between the Puente Hills (to the north) and Santa Ana mountains (to the south). Red dots mark the location of 2003 sampling sites for OSL dating. Blue circles mark 2004 samples. See figure 2 for regional location.



**Figure 4** - Map of Santiago Creek terraces at Irvine Lake. See figure 2 for regional location. OSL sampling locations (LG1, LG2 and LG3) are marked by red dots.



**Figure 5** - Map of locations of samples LG5 and LG6 (red dots) at Peralta Point, the westernmost tip of Loma Ridge. See figure 2 for regional location.

**Table 2 – Preliminary uplift rates derived from terraces**

Sample	LG1	LG2	LG3	LG4	LG6	LG7
Age (ka)	61.4	58.5	51.5	> 75	31.9	38.0
Error (ka)	6.9	7.3	5.4		4.8	3.9
D. Elev (m)	21	21	21	15	38	36
Uplift (m/ka)	<b>0.34</b>	<b>0.36</b>	<b>0.41</b>	<b>≤ 0.2</b>	<b>1.19</b>	<b>0.95</b>
Terrace	Qt2	Qt2	Qt2	Qt1	Qt1	Qt2
Location	Irvine Lake	Irvine Lake	Irvine Lake	Peralta Pt.	SAR PH*	SAR PH*

\*Santa Ana River, Puente Hills

### Non-technical summary

The main objective of this research is to better understand seismic hazard in Orange County, California, an area of nearly 3 million people. This project investigates possible tectonic deformation and earthquake potential associated with undiscovered faults in or near the Santa Ana Mountains and Puente Hills by examining the patterns carved by streams. The Santa Ana Mountains are prominent features in the landscape of the metropolitan Los Angeles basin. Comparable sized mountains and foothills in surrounding areas are known to be associated with active faults. Preliminary results indicate that the mountains are rising and may contain active faults.

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### **Availability of data**

Some of the DEM data and geomorphic analysis is posted on the web at <http://geolab.seweb.uci.edu/>. URLs for private pages with more results can be obtained by contacting project P.I. Lisa Grant ([lgrant@uci.edu](mailto:lgrant@uci.edu)), or Ph.D. student Eldon Gath ([gath@earthconsultants.com](mailto:gath@earthconsultants.com)). Project data will be archived in Gath's Ph.D. dissertation, which will become available through the UCI libraries.